TOPEX/POSEIDON AND JASON-1 COORDINATED NAVIGATION

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ABSTRACT *- This paper presents a study of the TOPEX/Poseidon and Jason-1 coordinated navigation effort performed by the TOPEX/Poseidon navigation team. Three mission phases are considered. First, coordinated navigation effort during Jason acquisition phase is presented. Formation flying during Jason cross calibration and validation phase is then discussed. Finally, the tandem mission is analyzed. It is the phase, which follows calibration during which the two satellites repeat a different ground track grid.*

INTRODUCTION

TOPEX/Poseidon is a joint US/France ocean topography experiment conducted by the National Aeronautics and Space Administration (NASA) and the Centre National d'Etudes Spatiales (CNES) to study ocean circulation and its interaction with the atmosphere, to improve our knowledge of climate change and heat transport in the ocean, and to study the marine gravity field. It was launched on August 10, 1992. Jason-1 is a follow-on mission conducted by the same organizations and is officially scheduled for launch on December 7, 2001. Like TOPEX/Poseidon, it is an oceanography mission to further monitor global ocean circulation, discover the ties between the oceans and the atmosphere, improve global climate prediction, and monitor events such as El Nino conditions and ocean eddies. It carries a radar altimeter, microwave radiometer, DORIS receiver, GPS receiver, and laser retro reflector array. Jason-1's main measurement goal, to determine the altitude of the satellite above the sea surface, must meet the required system accuracy of < 4.2 cm. (rms) with a goal of 2.5 cm. (rms). By meeting the required system altitude measurements, it continues the TOPEX/Poseidon scientific mission by:

1. Making high precession altimetry measurements in support of sea surface elevation and global ocean circulation studies

2. Providing near real-time sea-state data in support of marine forecasting and weather predictions.

To meet the above requirements and objectives, Jason-1 will repeat the TOPEX/Poseidon reference orbit given by the following mean classical orbital elements in the Earth equator and equinox of date:

Semi-major axis:	7714.4278 Km
Eccentricity:	0.000095
Inclination:	66.039 deg
Argument of perigee:	90 deg

The time of launch for Jason-1 is designed to place the satellite in an orbit plane close to the orbit plane of the TOPEX/Poseidon satellite, but also ensures that Jason-1 will not be in exactly the same orbit plane. For this purpose, two launch windows have been defined for each launch date with a 2-minute gap between them to preclude the launch in TOPEX/Poseidon's orbital plane or an orbital plane that is too close. If Jason-1 is launched in the first window, it will lead TOPEX/Poseidon and vice versa. Jason-1 will also keep the same ground track as TOPEX/Poseidon during the first 6 months of routine operations. Repeating the same ground track is necessary in order to cross-calibrate Jason-1's and TOPEX/Poseidon's performance. This choice is also essential to avoid any disruption or degradation in the use of the science data since it allows use of the TOPEX/Poseidon dedicated gravity field for orbit determination, to compare TOPEX/Poseidon's and Jason-1's measurements over the same sites, and to interpret the Jason-1 measurements without any delay with explicit reference to TOPEX/Poseidon altimetry mean profiles. The time phase between the two satellites is from 1 to 10 minutes (one minute is preferable) depending upon the launch time.

Jason-1 operation phases are defined as follows:

1. Launch phase (1 day): Begins one day before launch and ends shortly after injection.

2. Launch and Early Orbit Phase (LEOP, 2 to 5 days): Begins with launch phase and ends when the nominal satellite attitude has been reached.

3. Assessment phase (2 months maximum): Begins at end of launch phase and ends when the satellite is in operational orbit and both the satellite and the ground system are ready for routine operations.

4. Calibration/Validation phase (CAL/VAL, 6 months): Begins with the satellite in the operational orbit and continues until science data, instruments, and processing algorithms are satisfactory calibrated and validated.

5. Observational phase: Begins after the CAL/VAL phase and ends 3 years after launch.

Coordinated Navigation

This paper presents an effort by the TOPEX/Poseidon navigation team to coordinate navigation between TOPEX/Poseidon and Jason-1. Coordination between the satellites is required in two of the above operation phases; the assessment phase until Jason-1 acquires the operational orbit and the CAL/VAL phase formation flying needed for cross-calibration. The paper presents an independent design of a sequence of maneuvers for Jason-1 to acquire the operational orbit and place JASON in formation with TOPEX/Poseidon. This independent design is compared with the official CNES sequence in an effort to identify feasibility and risk of collision. After each Jason-1 maneuver the positions of the satellites are examined to ensure that relative navigation constraints are not violated. The paper also describes formation flying in the CAL/VAL phase. As in the acquisition phase, emphasis is given to maintaining the minimum vertical and along track separation between the two satellites. These minimum separations are 1 km. and 30 sec. respectively. After the CAL/VAL phase, TOPEX/Poseidon will be maneuvered to leave its orbit and drift to another orbit such that the two satellites will be in tandem. The new proposed TOPEX/Poseidon orbit will produce interleaved ground tracks with 1.4 degree longitude spacing from the Jason-1 tracks (current TOPEX/Poseidon tracks). A time offset of 0 day is also proposed. Such a tandem mission will provide a unique scientific opportunity and cost-effective approach to conducting new oceanic science investigations. The navigational aspects of the tandem mission are analyzed in this paper with emphasis on the cost of the phasing.

JASON-1 OPERATIONAL ORBIT REQUIREMENTS

The Jason-1 Mission has the same orbital characteristics as TOPEX/Poseidon. Its operational orbit will be a near-circular orbit with a frozen eccentricity. It will have an altitude of about 1336 km. and an inclination of 66 deg. The TOPEX/Poseidon orbit provides an exact repeat ground track in 127 revolutions that corresponds to a ground track repeat period of less than 10 days (9.9156 days). The orbital period is about 112 minutes.

Table 1 provides the Jason-1 injection mean orbital elements along with TOPEX/Poseidon reference orbit[1]. The orbit acquisition maneuver sequence was designed with the TOPEX/Poseidon reference orbit and reference grid as target parameters. The initial injection orbit assumes that the Jason-1 will be placed in an orbit with a semi-major axis (SMA) about 10 km. below the reference SMA of 7714.4293 km. A set of orbit adjust maneuvers is deigned to raise the orbit to the operational altitude and the proper phase.

TABLE 1. Mean Orbital Elements At First Ascending Node

Parameter	Injection Orbit	Operational Orbit	Change	Delta-V (m/s)
SMA (km)	7704.0634	7714.4293	10.3659	4.80
Eccentricity x 10^{-6}	498	95	403	-
Inclination	66.0396	66.0400	0.0004	0.05
AOP	89.9175	90.0	0.0825	-

The equatorial distance between two consecutive ascending nodes of the reference orbit is approximately 3156 km. and there are 9 ascending ground tracks between any two consecutive equatorial ascending node crossings.

Additionally an along-track separation between TOPEX/Poseidon and Jason-1 from ± 1 min to ± 10 min is required. This separation and the same ground track can be achieved by a difference in the right ascension of the ascending node. A minimum vertical separation of 1 km. (radial difference) is also a constraint for the orbit acquisition design.

Jason-1 Operational Constraints

The purpose of the orbit acquisition maneuver sequence is to acquire the operational orbit as quickly as possible. The maximum duration of the orbit acquisition was set at 40 days by the Jason-1 mission design team.

The Jason-1 propulsion module is designed to provide sufficient thrust and directional control to meet all orbit adjustment and maintenance maneuver requirements. The propulsion subsystem is capable of implementing maneuvers of up to 2.5 m/s per burn.

DESIGN STRATEGY

The orbit acquisition maneuver sequence should accomplish several objectives. In addition to raising the semi-major axis, both the eccentricity and the argument of perigee must be adjusted to the desired frozen values. The sequence of orbital burns used to acquire orbital parameters must also acquire the desired reference ground track pattern (TOPEX/Poseidon ground track). Any inclination error caused by the launch vehicle must be removed. The orbit acquisition process ends when the ground track is within the ± 1 km control band.

The following design strategy was implemented in the orbit acquisition study:

a) The design consists of a sequence of In-Plane Maneuvers (IPMs) and an inclination maneuver (out of plane) if required

b) The first IPM, called CAL (calibration), is to check the propulsion system

c) The eccentricity vector can be adjusted by positioning of the along-track maneuvers in the orbit

d) Parametric variables for successive maneuvers consist of selection of the target reference track (TOPEX/Poseidon track), the maneuver magnitude, and the number of maneuvers

e) Relative mean ground track drift rate of the injection orbit remains the same until a maneuver is implemented

f) The relationship between the injection and reference orbit tracks is almost linear and is determined by the relative drift rate. This relation holds after every maneuver

g) The changes in the relative drift rates are accomplished through along-track maneuvers.

Maneuver Design Sequence

The maneuver sequence design was performed using the Orbit Acquisition Maneuver Software (OAMS)[2]. This software is an analytic orbit propagator that allows for the execution of a single impulsive maneuver that is performed at a specific orbital location within a particular orbit. Its dynamic model includes earth gravity and luni-solar perturbations but ignores drag, as its effect is negligible over the period between successive orbit acquisition maneuvers. The TOPEX/Poseidon Double Precision Trajectory software (DPTARJ) was used to compare the results with the TOPEX/Poseidon orbit and identify any possible collision risk.

The evolution of the ground track phasing from injection to the operational orbit is represented in terms of the ground track drift rate and the history of ascending node-crossing longitudes. The equation of the ground track phasing is:

$$D_0 - d_0(t_1 - t_0) - d_1(t_2 - t_1) - \ldots - d_{n-1}(t_n - t_{n-1}) = 0$$

where:

D_0 = equatorial distance between the nominal ground track and the actual ground track at first ascending node.

d_0 = ground track relative drift rate at the first ascending node.

t_0 = time of the first ascending node.

d_i = ground track relative drift rate after i^{th} maneuver.

t_i = i^{th} maneuver time.

Error Sources

The error sources affecting the maneuver design are injection errors, maneuver execution errors and orbit determination uncertainties. The possible injection errors are the dispersion in semi major axis, eccentricity, inclination, and right ascension of the ascending node. The error in inclination requires a separate burn to correct the angle. By adjusting the along-track maneuver magnitudes the errors in orbital parameters of SMA, eccentricity, and AOP can easily be corrected. The maneuver execution errors include thruster's performance, velocity magnitude errors, and satellite pointing errors. The errors associated with orbit determination are negligible after 48 hours of GPS, and DORIS tracking solutions.

Maneuver Design

Three types of maneuvers are considered in the Jason-1 orbital acquisition maneuver sequence.

a) One initial calibration burn is scheduled to test the thruster performance

b) An inclination correction burn

c) Along-track maneuvers to adjust the semi-major axis and eccentricity vector

Table 2 presents the Jason-1 initial orbital elements after injection (1st ascending node), mean J2000 reference frame: (from Mission Analysis for Jason-1, edition 4, with RAAN modified to correspond to a longitude of 59.219 deg East)

Table 2. JASON initial orbital elements after injection

Time (UTC)	02/28/2001.01:57:25.623
SMA	7704.06340
Eccentricity	0.000498277
Inclination	66.039608
RAAN	246.534953
AOP	89.917450
MA	270.137656

Maneuver Sequence

The following sequence of independent maneuvers is closely modeled after the successful sequence of orbit acquisition maneuvers performed for TOPEX/Poseidon mission in Aug./Sept. 1992[(3)].

IPM1 (CAL): The main objectives of the first relatively small burn is to confirm the satisfactory operation of the thrusters, to determine the burn scale factor, and to get a better understanding of the execution errors (delta-v ≈ 0.1 m/s)

IPM2: This is the first large maneuver designed to reduce the drift and raise the SMA value (delta-v ≈ 2 m/s)

IPM3 and IPM4: This is a rendezvous maneuver composed of two burns, that are apart 180 deg in the same orbit. This maneuver helps to simultaneously correct eccentricity and raise SMA value (delta-v ≈ 2.5 m/s)

IPM5: This medium burn is designed to stop the residual drift (delta-v ≈ 0.1 m/s)

IPM6 / Orbit Maintenance Maneuver (OMM1): This is the final touch-up maneuver to place the ground track within the control boundary (delta-v ≈ 10 mm/s)

Figures 1 through 3 show the Jason-1 longitude error reduction, drift rate reduction, and semi-major axis history, respectively:

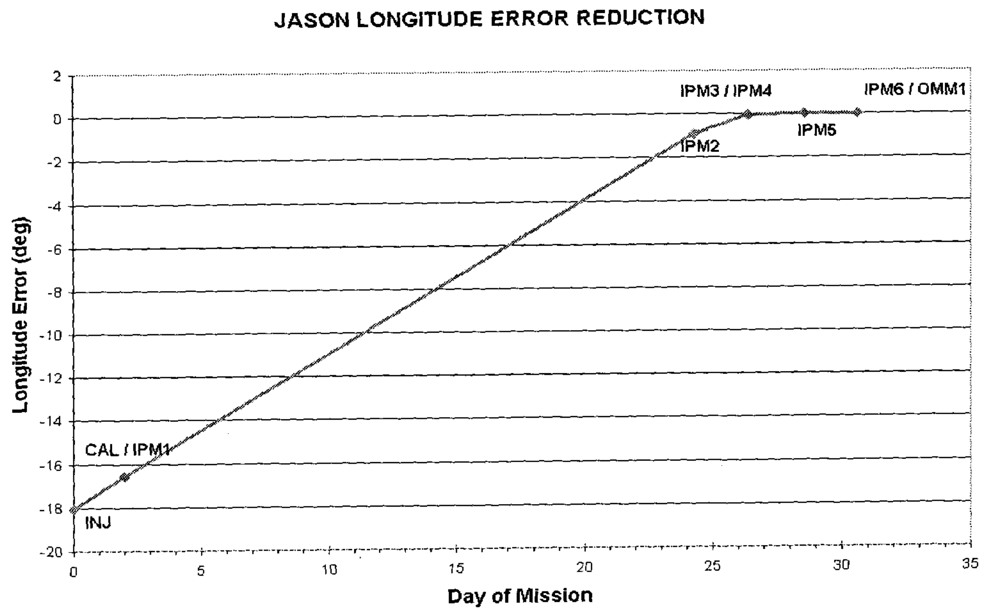

Fig. 1. Jason-1 Longitude Error Reduction

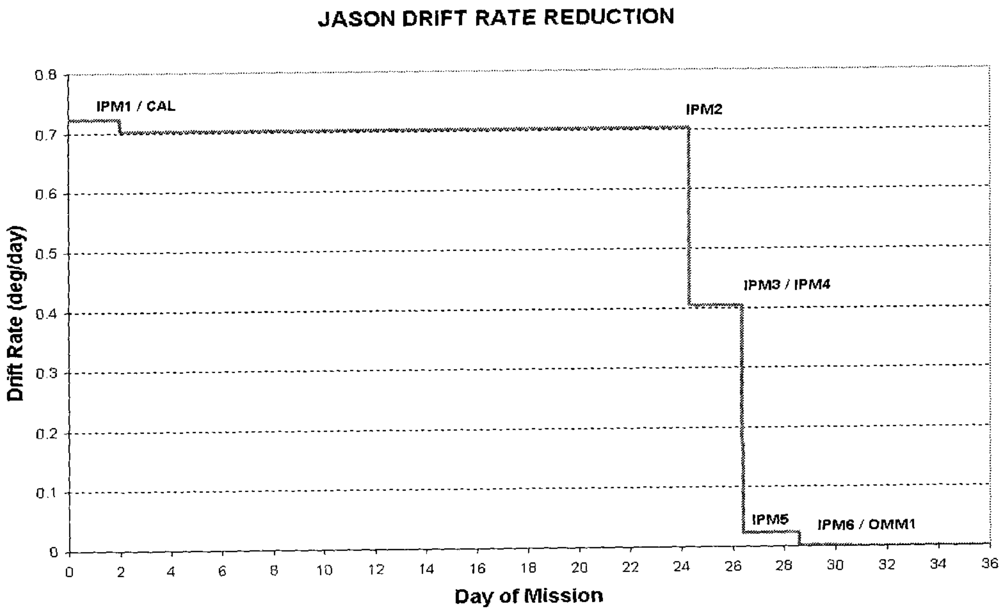

Fig. 2. Jason-1 Longitude Drift Rate Evolution During Orbit Acquisition

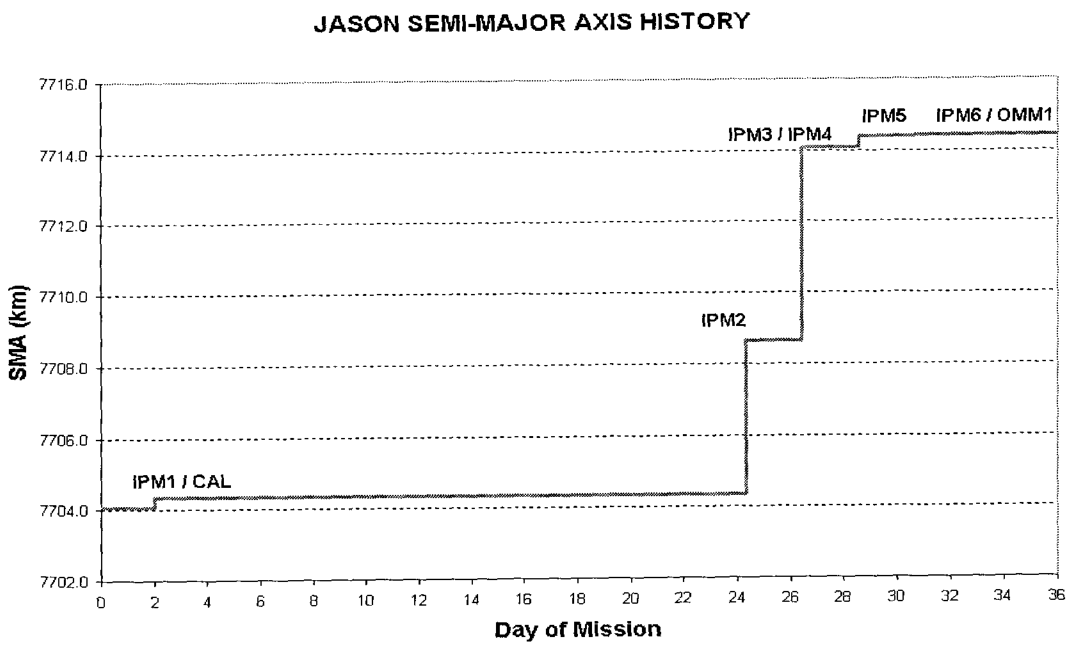

Fig. 3. Jason-1 Semi-major Axis Evolution During Orbit Acquisition

The results of the set of maneuver sequence performance is tabulated in Table 3 using the values obtained from running OAMS program:

Table 3. Baseline Maneuver Sequence Performance Characteristics

Man. No.	Day from Injection	Rev. No.	Man. Type	Man. Loc. (deg)	GT drift rate (east deg/day)	Delta-V (mm/s)	Typical Delta-V Error (3%)
0					0.723342		
1	2	26	IPM1/ CAL	270	0.703366	133.7	4.02
2			Inclination				
3	25	312	IPM2	263	0.403640	2005.3	60.16
4	27	338*	IPM3	90	0.173777	1537.4	46.12
5	27	341*	IPM4	270	0.023944	1002.7	30.08
6	29	368	IPM5	90	0.001960	147.06	4.41
7	31	393	IPM6/OMM1	90	0.000589	9.28	0.28

* Rendezvous burns performed 180° apart in the same orbit

Orbit Acquisition Results Relative to TOPEX/Poseidon's Orbit

The independent set of orbit acquisition maneuvers places JASON-1 within the control boundary in operational orbit. The results were compared with the orbit of TOPEX/Poseidon.

Figures 4 and 5 represent the orbital differences of Jason-1 and TOPEX/Poseidon from the injection orbit until the two spacecraft are within their repeat ground track control boundaries. Figure 6 shows how Jason-1 enters the ground track dead-band and the effect of the last orbit acquisition maneuver.

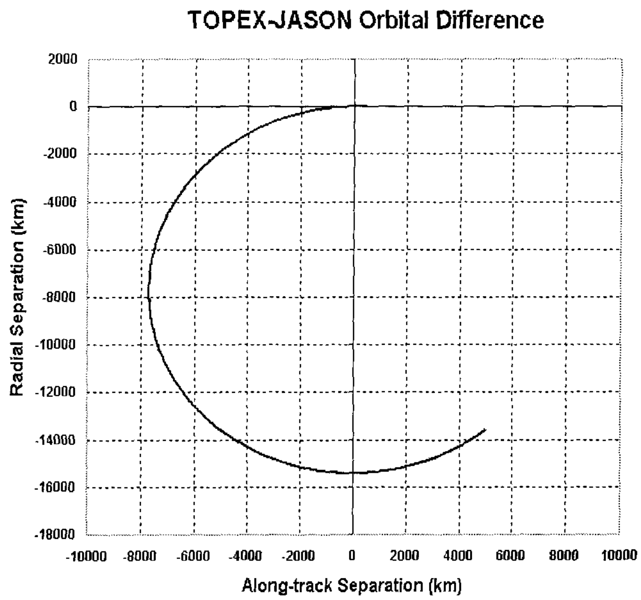

Fig. 4. TOPEX/Poseidon Jason-1 Orbital Difference

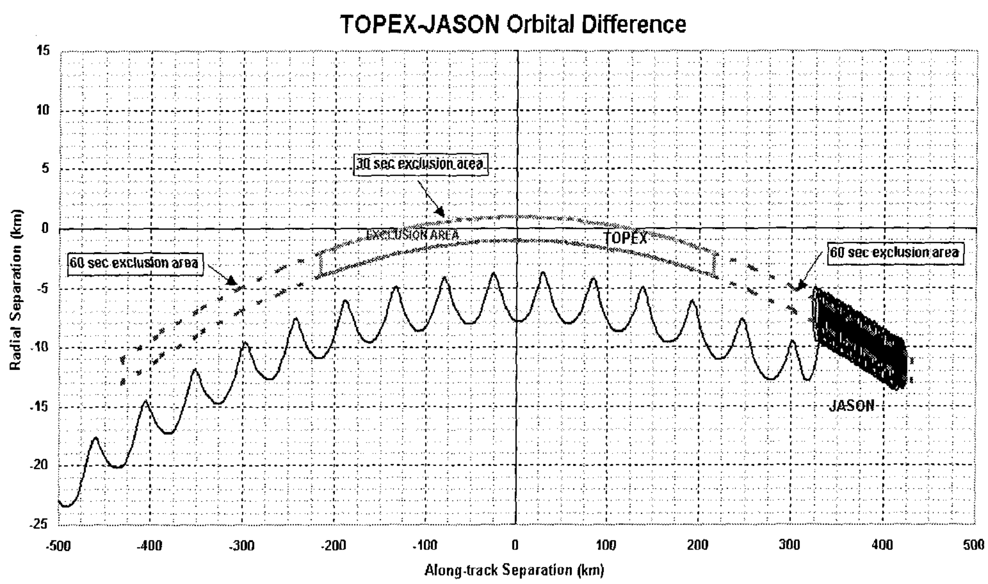

Fig. 5. TOPEX/Poseidon Jason-1 Separation Box Requirements and Final Acquisition

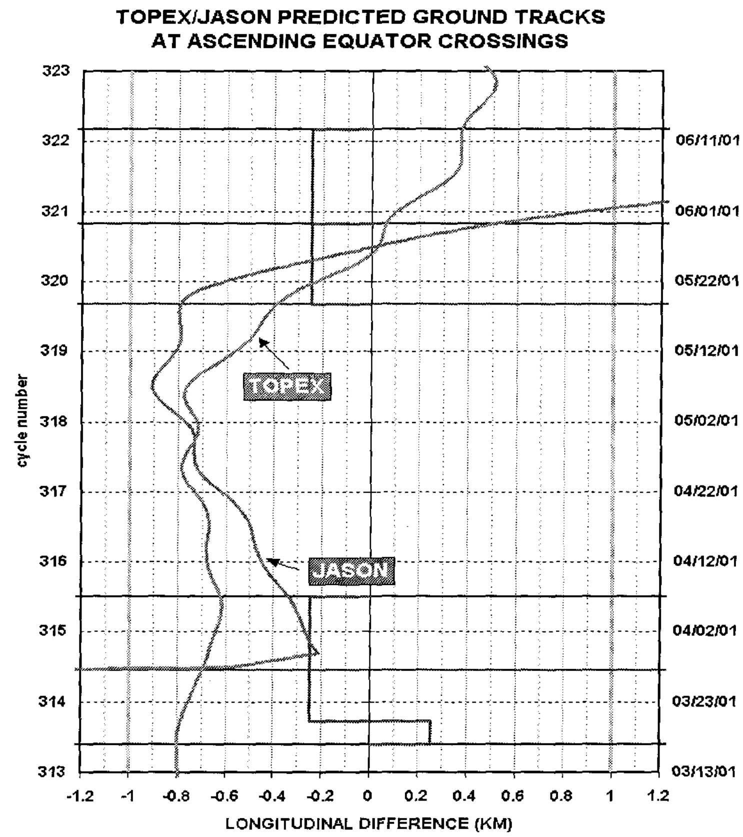

Fig. 6. TOPEX/Poseidon Jason-1 Ground Track Deviation at the Ascending Node at the End of the Acquisition Phase

The baseline maneuver sequence achieves the operational orbit in 29 days. This design sequence maintains the 1 km. vertical and minimum 30 sec. along track separation requirements. The risk of collision of the two satellites is considered minimal.

FORMATION FLYING DURING THE CAL/VAL PHASE

After Jason-1 successfully acquires its operational orbit the two spacecraft have to be maintained in their orbit so their respective altimeters can be cross-calibrated. This is called the Calibration/Validation (CAL/VAL) phase. This phase is of extreme importance for the science goal of obtaining a continuous, self-consistent time series of altimeter data that encompasses TOPEX/Poseidon, Jason-1 and follow-up missions. Only a successful cross-calibration will allow the study of long-term phenomena like the ocean rise caused by global warming.

TOPEX/Poseidon is operated by NASA/JPL while Jason-1 will be operated by CNES. The two navigation teams will need to coordinate their activities in order to make the joint mission a success.

Formation Flying Concept

When the two spacecraft are in their orbits for the CAL/VAL phase, their mean orbital position should be such that they both are within ±1 km of the nominal ground track and their over-flights of a particular point on the earth surface are separated between 1 and 10 minutes. These requirements impose that the two spacecraft should be in the same orbit, but with different right ascension of the ascending node and different anomaly. Figure 7 shows this relationship.

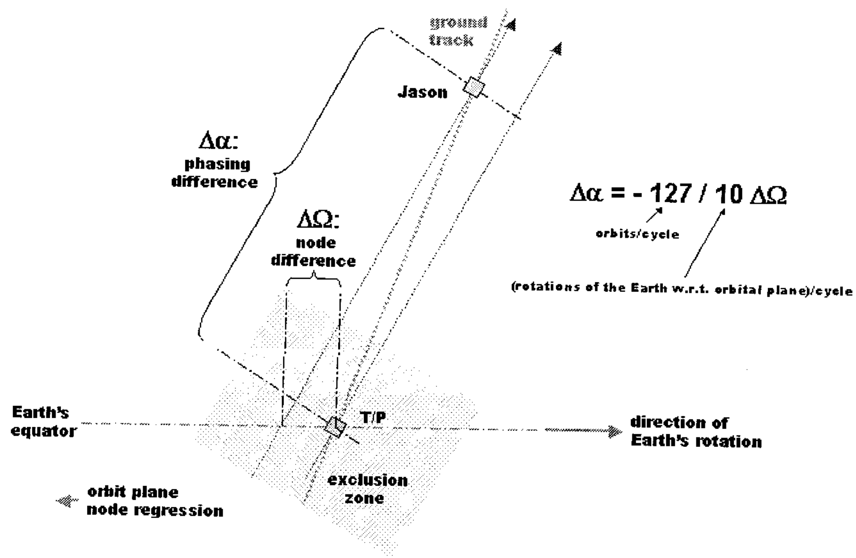

Fig. 7. Formation Flying Concept

Differences Between TOPEX/Poseidon and Jason-1

One of the difficulties for the formation flying of the two spacecraft is going to be the notable differences in ballistic coefficients. Table 4 shows the properties of the spacecraft that are relevant to the relative navigation.

Table 4. Spacecraft Properties

	TOPEX/Poseidon	Jason-1
Mass	~ 2406 Kg	~ 483 Kg
Typical Drag Area	18 m^2	8 m^2
Drag Area / Mass Ratio	0.0075 m^2/ Kg	0.0166 m^2/ Kg
Attitude transition (betaprime)	30°	15°
Solar array pitch bias	~ 40°	0°
Semi-major axis boost per fixed yaw period	Up to 4 m	Probably 0

Jason-1 has a ballistic coefficient that is less than half of TOPEX/Poseidon's ballistic coefficient. This means that it is going to be affected by drag more than TOPEX/Poseidon, and in particular, its semi-major-axis decay rate is going to be at least twice that of TOPEX/Poseidon. TOPEX/Poseidon also utilizes a solar array pitch bias in order to use solar radiation pressure to boost the orbit when the spacecraft attitude is fixed-yaw[4].

IMPLEMENTATION OF FORMATION FLYING

Once Jason-1 has acquired its operational orbit, the separation between both spacecraft will depend on the particular nominal orbit for Jason-1 and the position of each spacecraft within the ground track dead-band. The nominal orbit for Jason-1 will determine the mean separation between the two, from 1 to 10 minutes depending on the ascending node separation. The position of each satellite within the dead-band will change their separation by up to 4.3 seconds, the worst case being when the lead spacecraft is near the western threshold and the trailing spacecraft is near the eastern threshold.

Analysis shows that luni-solar effects mainly govern the evolution of the time of the ascending nodes for TOPEX/Poseidon. Figure 8 depicts the difference between the actual ascending node time and the time as calculated from the mean nodal period. If the effect of the position within the dead-band is removed, then the maximum deviation only amounts up to ± 4 seconds. Because the luni-solar perturbations will be almost identical for TOPEX/Poseidon and Jason-1, this deviation will be common and will not affect their relative separation.

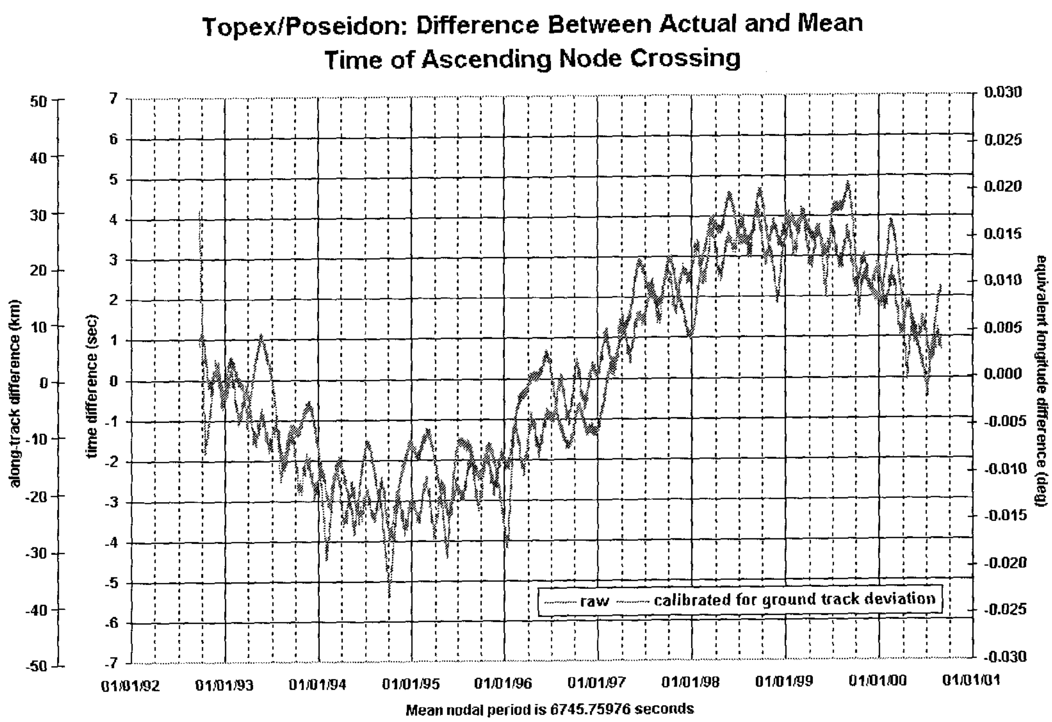

Fig. 8. Ascending Node Deviation for TOPEX/Poseidon

Comparisons between CNES and JPL Orbit Propagation Software

Cooperation between the TOPEX/Poseidon and Jason-1 navigation teams is necessary to maintain the required separation requirements and avoid a collision between both spacecraft. Use of two different navigation software and tools by CNES and JPL for orbit propagation introduces differences in ground track predictions and orbital elements. Pre-flight comparisons were made between the orbit propagation results of CNES and JPL software to determine if the differences exceed the accuracy requirements.

Five different test case results containing several combinations of various non-two body perturbing accelerations were analyzed. The perturbation models included Earth gravity expanded for oblateness and uneven distribution of mass, gravitational effects from the Sun and the Moon modeled as point masses, drag acceleration from aerodynamic interaction with the sparse upper atmosphere, and solar radiation pressure resulting from direct sunlight illumination and reflections from the Earth.

The force model of each test case was propagated for a 30-day period of free flight by the two navigation software, and the resulting ephemerides and ground tracks were compared for compatibility. The criteria used for assessment purposes were extracted from the one-sigma accuracy requirements on the Operational Orbit Ephemeris enforced in the current operation of the TOPEX satellite. These included a ground track repeatability of ± 250 meters at the ascending node after 30 days and a set of requirements for the state vectors.

From the ground tracks generated by the two navigation software for the five test cases, it was determined that the maximum differences at the equator ranged from –25.9 to 19.0 meters, well within the ± 250 meters required in TOPEX. The ephemerides generated also produced acceptable differences in the position and velocity components relative to the accuracy requirements for TOPEX, with increases bounded by an order of magnitude. Tables 5 and 6 list the results for a test case that considers all the perturbations. For this particular case, the maximum equatorial ground track difference observed was 14.5 meters. From the favorable agreement between the ephemerides and ground tracks, it was thus concluded that the CNES and JPL navigation software were compatible with the accuracy requirements.

Table 5. Position differences seen between independent runs of CNES and JPL software

Position differences (m)	Min.	Max.	Mean	Sigma
Radial	-76.2	77.4	-2.2	53.7
Along Track	-131.4	184.6	+33.0	110.2
Cross Track	-63.4	63.6	+3.5	45.6

Table 6. Velocity differences seen between independent runs of CNES and JPL software

Velocity differences (mm/s)	Min.	Max.	Mean	Sigma
Radial	-100.4	51.2	-27.0	51.5
Along Track	-71.9	71.0	+2.2	50.0
Cross Track	-59.1	59.2	-1.8	41.2

From the previous discussions, we can conclude that maintaining the separation between both spacecraft (plus or minus a 4.3 second separation) can easily be maintained if both satellites fly within the ground track dead-band. Jason-1 will need to be maneuvered about twice as often as TOPEX/Poseidon, and the typical maneuver magnitude for Jason-1 will be about double than that for TOPEX/Poseidon. Comparisons between CNES and JPL software orbit propagation results fall within acceptable tolerances and helps ease future coordination efforts between the TOPEX/Poseidon and Jason-1 navigation teams.

COLLISION RISKS DURING THE CAL/VAL PHASE

During the Calibration/Validation phase the two spacecraft are going to fly in almost the same orbit, with an along-track separation of between 1 an 10 minutes, with 1 minute being the optimal separation. Because of the age of TOPEX/Poseidon, that was launched in August 1992 and was designed for an operational life of five years, there is a possibility that it could become uncontrollable during the CAL/VAL phase. A more remote possibility is that Jason-1 could become uncontrollable during that phase. In any of these two hypothetical cases, the uncontrollable satellite cannot be maneuvered and it will freely decay. The worst case is that in which the uncontrollable satellite is trailing, because as it decays in the absence of altitude control maneuvers, it will also get closer to the leading satellite. An uncontrolled Jason-1, under current, relatively high, solar activity conditions, will reach the orbital position of TOPEX/Poseidon in about 120 days, and at that time the drop in semi-major axis will be of only 30 meters. If TOPEX/Poseidon is trailing and uncontrollable, then it will reach the orbital position of Jason-1 in about 180 days with a 20 meter drop in semi-major axis. In any of the two cases, there would be plenty of time to plan for collision avoidance maneuvers, but at the cost of missed science observations during the time in which the active spacecraft is in a higher, safer orbit.

The preferred launch windows for Jason are the launch times that allow Jason to lead while TOPEX/Poseidon trails with a one-minute separation.

TANDEM MISSION

The overlapping tandem phase of the TOPEX/Poseidon and Jason-1 missions will provide unprecedented opportunities for oceanographic studies by using the two high-precision altimeters of TOPEX/Poseidon and Jason-1. One aspect of this tandem mission is maneuvering TOPEX/Poseidon to acquire a new orbit to establish an orbit phasing to meet science requirements. In the last Science Working Team Meeting (SWT)[5,6] two main options for TOPEX/Poseidon future orbit were discussed. One option is to move TOPEX/Poseidon sidewise to an interleaving track, and the other option is to keep it on the same track grid with some time offset to Jason-1. The conclusion/recommendation of the SWT was to move TOPEX/Poseidon to an interleaved orbit that is simultaneous to Jason-1 but shifted by 1.4-degree track. Since there was no strong scientific desire as indicated by the SWT to specify certain time offset between the two satellites equatorial crossing times and duration of phasing, time offset and duration of phasing will be determined by satellite constraints and issues.

Figure 9 shows the cost of phasing the TOPEX/Poseidon orbit for the tandem mission. It relates the delta V required with the duration of phasing for the single integer number of days offset case (same track grid with offset) as well as the 1.4-degree longitude spacing. In the single integer number of days offset case, the true anomaly phase shifts +/-36, +/-72, +/-108, +/-144, +/-180 degrees represent adjacent tracks the spacecraft flies over on days 8, 5, 2, 9, 6 of the cycle for positive phasing. Negative true anomaly phasing represents tracks the spacecraft flies over on days 4, 7, 10, 3, and 6 of the cycle. The recommended 1.4 degree longitude spacing case is shown in the figure as curves of true anomaly phase shifts of +/-18, +/-54, +/-90, +/-126, +/-162 degrees. Increasing duration of phasing helps to reduce the total delta V required as follows:

- One cycle: about 2, 6, 9, 13, 17 meters/sec
- Two cycles: about 1, 3, 5, 7, 8 meters/sec
- Three cycles: about 1, 2, 3, 5, 6 meters/sec

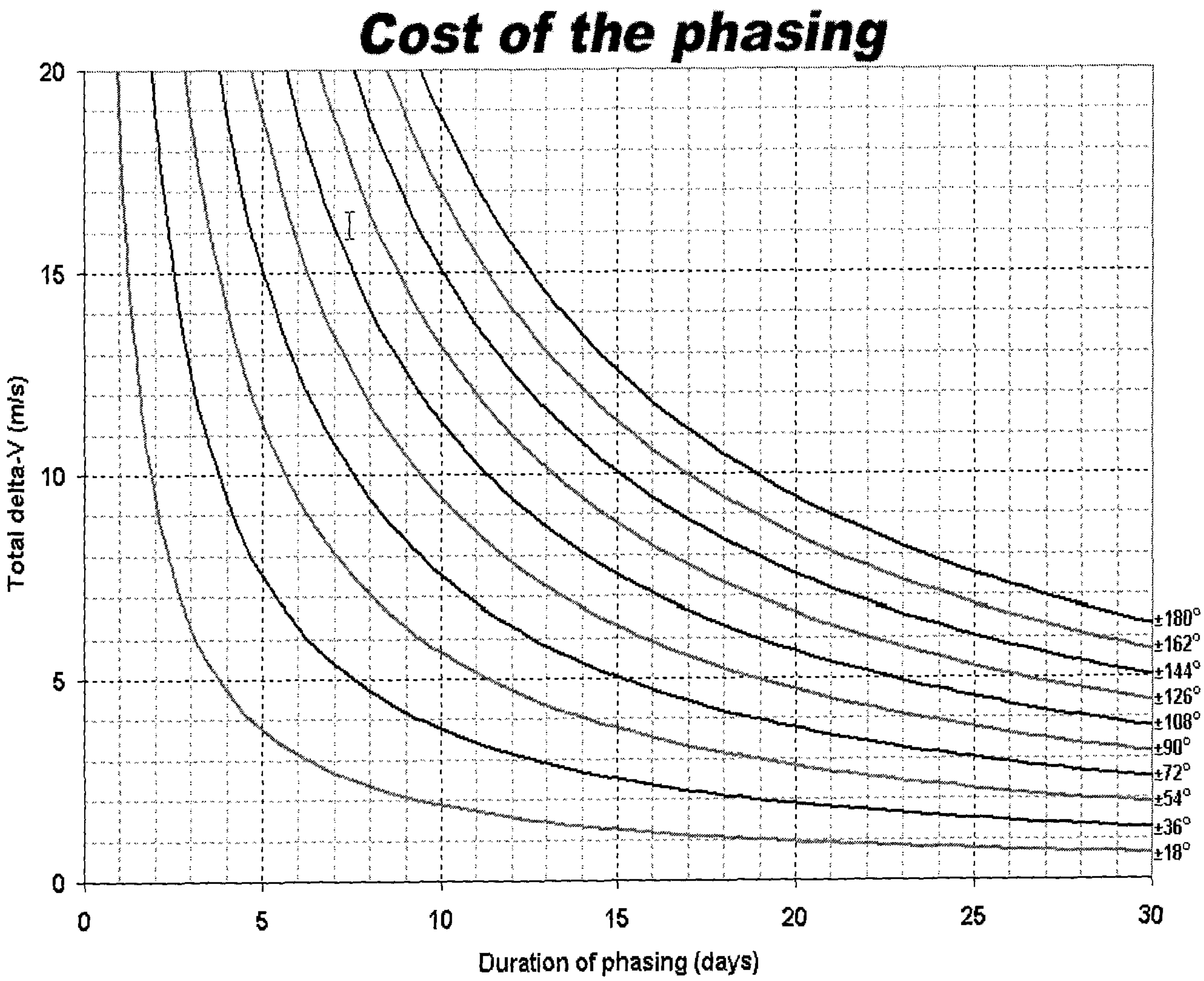

Fig. 9.

As a result of the TOPEX/Poseidon satellite issues and constraints, an 18 deg phase shift is proposed. (TOPEX/Poseidon and Jason-1 are separated by 18 degrees in true anomaly). This provides the lowest delta V required to place TOPEX/Poseidon in tandem mission with Jason-1. Based on this proposal the total delta V required is as follows:

- One cycle: about 2 meters/sec
- Two cycles: about 1 meter /sec
- Three cycles: about 1 meter/sec

The above delta V is the sum of two delta V's of equal value. The first is to change the semi-major axis (period) to start a drift relative to Jason-1 track and the second to stop the drift (restore semi-major axis) at 1.4 degree longitude spacing.

Since all maneuvers to change the orbit are semi-major axis maneuvers, there are no significant satellite/navigational issues except for the inherent risk of doing large maneuvers (OMMs are in mm/sec only). Currently, TOPEX/Poseidon has about 200 kg. of propellant and has the capability to do a delta-V of 187 meters/sec. So, the issue is not resources but using satellite systems not normally executed and/or beyond limits seen in normal operations. The navigation team recommends using the 22 N thrusters to execute these maneuvers. In case of problems with the 22 N thrusters, we recommend a strategy of several maneuvers using the 1 N thrusters (each of a few hundred mm/sec). TOPEX/Poseidon executed maneuvers of that magnitude using the 1 N thrusters earlier in the mission in the acquisition phase.

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